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# UNITED STATES PATENT APPLICATION

## GUTTER FILLERS AND PACKS WITH ENHANCED FLUID FLOW


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# GUTTER FILLERS AND PACKS WITH ENHANCED FLUID FLOW

## Related Applications

This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/490,725, filed July 29, 2003; the disclosure of which is incorporated herein by reference in its entirety.

## Technical Field

The present invention relates to materials composed of fibers, foam, sponges and other materials in a high loft, low density, porous, orientated structure that can be used as a filler in gutters.

## Background Art

Gutters are designed to channel fluids (rain, molten snow, etc.) away from the structure to a down chute that will lead away from the structure. A problem with gutters is that they are exposed to the environment and can be blocked and clogged by leaves, falling tree debris, dirt, etc. The blockage can lead to structural problems and the organic matter left in the gutters can decompose and create potential health problems. The current solutions include baffles, covers and similar structures that cover the gutter preventing leaves and other materials from getting into the gutter as well as a foam filler material. In most cases, these are not effective and annual cleaning is typically required to alleviate the problems with blockage. Many of these protection devices/shields/guards need to be installed professionally, and

may need significant maintenance. Representative prior art patents include the following:

| PATENT NO. | ISSUE DATE |
|---|---|
| US 6,533,941 | March 18, 2003 |
| US 6,520,254 | February 18, 2003 |
| US 6,202,750 | March 20, 2001 |
| US 6,427,388 | August 6, 2002 |
| US 6,406,620 | June 18, 2002 |
| US 6,363,662 | April 2, 2002 |
| US 6,357,183 | March 19, 2002 |
| US 6,205,715 | March 27, 2001 |
| US 6,164,020 | December 26, 2000 |
| US 6,134,843 | October 24, 2000 |
| US 6,047,502 | April 11, 2000 |
| US D417,264 | November 30, 1999 |
| US 5,848,857 | December 15, 1998 |
| US 5,729,931 | March 24, 1998 |
| US 5,592,783 | January 14, 1997 |
| US 5,566,513 | October 22, 1996 |
| US 5,535,554 | July 16, 1996 |
| US 5,509,500 | April 23, 1996 |
| US 5,452,546 | January 14, 1995 |
| US 5,438,803 | August 8, 1995 |
| US 5,271,191 | December 21, 1993 |
| US 5,103,601 | April 14, 1992 |
| US 5,092,086 | March 3, 1992 |
| US 5,072,551 | December 17, 1991 |
| US 5,056,276 | October 15, 1991 |
| US 4,965,969 | October 30, 1990 |
| US 4,937,986 | July 3, 1990 |
| US 4,932,498 | June 12, 1990 |
| US 4,841,686 | June 27, 1989 |
| US 4,813,515 | March 21, 1989 |
| US 4,750,300 | June 14, 1988 |
| US 4,907,381 | March 13, 1990 |
| US 4,876,827 | October 31, 1989 |
| US 4,586,298 | May 6, 1986 |
| US 4,473,973 | October 2, 1984 |
| US 4,404,775 | September 20, 1983 |
| US 4,395,852 | August 2, 1983 |
| US 4,351,134 | September 28, 1982 |
| US 4,036,761 | July 19, 1977 |
| US 3,855,132 | December 17, 1994 |
| US 3,121,684 | February 18, 1964 |

More specifically, many systems and devices have been used to prevent leaves, twigs, pine needles, pollens or roofing materials from entering into rain gutters and thus downspouts.

U.S. Patent No. 3,121,684 discloses a downspout strainer device placed into the upper end of a downspout by the use of a long pole having a hook at its upper end that engages the wire loop of the device. The strainer allows rain water to pass through it while preventing the debris entering the downspout. However, debris still enters the gutter and clogs it in time. This device also requires periodical removal and cleaning out of the accumulated material caught by the device. During heavier rainfalls such as in fall season, the strainer can catch enough leaves during a single rainfall to clog entry to the down spout.

Many devices have been developed to prevent foreign materials from entering the rain gutters and downspouts. For example, gutter guards made of wire mesh are unrolled prior to attachment to the gutters since these are present in rolled form. Also, the wire mesh can be deformed during manufacture, shipment and even during attachment. Most of the time, these wire meshes deform and gutters are still exposed to debris.

U.S. Patent No. 4,351,134 discloses an improved wire mesh and presents a hinged gutter guard device in the form of an elongated perforated cover plate made of a relatively rigid material having hinge straps. Hinge straps are positioned within longitudinal slots and are adapted to be secured to a roof beneath the lower course of shingles. The straps can be shifted within their slots to ensure proper attachment. However, shingle debris can still pass through perforations and the gutters still must be cleaned. Further,

especially in heavy rainfalls, the force of the rain water off the roof can cause part of the water to skid off the gutter guard and fall directly on the lawn below causing pitting or trenching. In time, the stress variation caused by normal use and raising-lowering of the gutter guard weakens or tears shingles, thus necessitating replacing or repair of the shingles.

Another patent, U.S. Patent No. 4,841,686 discloses a filter attachment that fits over the gutter trench. The filter attachment is clamped with a pad of fibrous material, fiberglass, underneath it. The screen has 0.25 to 0.5 inch square openings. These openings can trap smaller particles but in time the surface of the screen clogs thus needs to be cleaned out. The cleaning process is time consuming and difficult for most of the time.

U.S. Patent No. 3,855,132 discloses a fitted porous solid polyurethane foam material that serves as a barrier to leaves, dirt, etc. Here, there is a space between foam material and the bottom of the gutter that allows for free flow of water below the porous section while blocking the debris. The percentage void volume is critical since higher void volume increases the water transfer capacity. In this particular patent, the polyurethane foam has 95 % void volume with an average of 10 pores per linear inch.

U.S. Patent No. 5,848,857 provides an inexpensive, easy to manufacture, easy to install rain gutter shield which filters out not only large but also small foreign material permitting only rain water and other easily washed away materials to pass into the downspout. The gutter shield here has an elongated layerless screen of porous nonwoven polymeric fiber material. The porous nonwoven fiber material is a 1/8" to ½" thick mat of

silicon carbide-polyamide fiber/flint fiber. These types of nonwovens are known in the market. It is possible to purchase these in roll form and cut into various lengths to utilize them in a rain gutter. Also, 3M company provides silicon carbide/nylon/aluminum oxide type of material known as BEAR-TEX™ nonwoven material. The rain gutter shield can be attached to the gutter at the time of mounting or be attached to already mounted rain gutters. The main filtering function is provided by the porous nonwoven polymeric fiber itself. The material is claimed to be weather resistant, flexible enough to be handled, sturdy enough to avoid sagging and stretching without the need for a backing layer. Also, it quickly lets rain water pass through it while filtering the fine solid materials.

U.S. Patent No. 6,134,843 takes this one step further and provides a rain gutter shield that can be used with any type of existing rain gutters on most roof designs. It is disclosed that a gutter shield is provided that is economical to manufacture and install and also not adversely affected by heat or cold. The gutter shield has matting and a covering. The matting is an elongated three dimensional matting that includes plural shapes of rows, the basis of the shapes defining a first plane and the apexes of the shapes defining a second plane. The matting extends outwards from the bases. The covering is an elongated water porous fabric that has an upper and lower surface. The upper surface is smooth enough to prevent debris from being retained by the fabric material and enables debris to be blown off by ambient winds. The lower surface of the fabric is bonded to the matting. One longitudinal edge of the fabric extends outwards for the mounting device to the building and the other edge of the fabric extends for attachment to the

outer lip of the gutter. This positions the shield over the opening of the gutter effectively. The plural shapes mentioned above are cones made of NYLON® that has carbon black to resist the detrimental effects of UV light. The cones are arranged in transverse and longitudinal rows. The fabric mentioned is a porous NYLON®-polyester nonwoven fabric such that when the rain or snow is gone, the debris will naturally dry and be blown off by winds. The nonwoven fabric is heat bonded to the matting. Fabric extends outward in the first plane, in both transverse directions to the length of the gutter. A portion of the fabric extends to the outer lip of the gutter to prevent debris entering the device.

Some prior gutter guards (U.S. Patent No. 6,205,715) include gutter screens made of woven metal wire that prevents debris from entering the gutter. Metal wire screens are expensive to manufacture and install compared to nonmetal screens like plastic or NYLON® screens. Metal screens can also be awkward to remove to do the cleaning of the gutter. In addition to this, if the metal wire does not have a large enough gauge, the debris, the weight of water running off the roof onto the screen or the weight of the debris that lands on the screen well form valleys on the screen. These valleys then collect debris and interfere with the water collection. Thus, this requires cleaning later on.

There are also several commercial products designed to protect gutters from clogging that are well known but are not the subject matter of patent protection.

For example, *FLOW FREE™* gutter protection system is one of these products that provides a 0.75 inch thick NYLON® mesh material designed to

fit in five inch K type gutters. This device fits over the hanging brackets of the gutters and one side extends to the bottom of the gutter to prevent its collapse in to the gutter. But, this system is precut and fits only to 5 inch K type of gutters while may home owners have other types of gutters. In this particular type, the NYLON® mesh traps pine needles, shingle material, and the like and should be cleaned to avoid blocking of the flow of rain water.

*GUTTER HELMET®* is a commercial product for gutter protection. This device covers most of the gutter with a bullnose shaped protrusion proximate the outer edge of the gutter. The design is based on utilizing surface tension of water thus channeling the water down the bullnose in to the gutter while leaves and other debris falls down. Most of the commercial GUTTER HELMET® are affixed to the edge of the roof by screws that lead to leaks through the roof. Unless the bullnose is completely wetted, gutter helmets are not efficient and water drips directly onto the lawn causing soil erosion and water in the building basement. In winters, the dripping water causes icicles to form and can fall becoming a safety hazard. Also, dirt mildew builds up on the bullnose preventing water flow into the gutter and necessitates routine scrubbing and cleaning of the system, and in some installations gutter helmets are known to buckle from the heat of the sun. At the time of cleaning, the device needs to be removed from the gutter also, which makes cleaning harder.

The *GUTTER PROTECH™* gutter protection system also uses surface tension and liquid adhesion of rainwater to direct it into the gutter trench through two rows of alternating angled slots over mini-bullnoses. As in similar designs, until the bullnoses sufficiently get wet, they do not work

properly and dirt builds up on them and must be routinely cleaned to ensure flow into the gutters.

*WATERFALL*™ plastic gutter guard system is another commercial product present in the market. The system also uses the principle of water adhesion and includes two sets of parallel channels each having drain holes. Rain water flows from the roof onto the device into the upper channel and into the gutter trench. The second lower channel collects the remaining runoff and directs it into the gutter. The classical problem of debris accumulation with gutter guards occurs here once again. Parallel channels need to be cleaned out periodically. Since this is a rigid PVC gutter system, it cracks in cold weather thus degrading its performance and requiring replacement. Further, the device does not include end caps so birds gain entry into the gutter and build nests. Another issue with this particular commercial product is that it tends to separate from beneath shingles and be blown off the gutters.

None of the systems described above are highly effective in keeping all 'debris out of gutter systems. Eventually, debris builds up either on the surface of the devices or within the gutter drenches and/or downspouts.

The invention described herein is intended to overcome many of the well-known deficiencies of prior art gutter guard devices and to provide a new and improved gutter pack or gutter fill material.

## Summary

A porous, low density, resilient, filler material that can be cut to shape, molded and fitted into a gutter in place of typical gutter guards or shields that

partially cover the gutter has been developed. The present embodiment comprises a high loft, sponge-like material made from fibers, foam, or other similar materials to create a material that can be packed into the gutter. The structure is high in porosity such that the pores and the capillaries are elongated in the direction of the flow to achieve the highest flow rates possible. Foreign objects such as leaves, pine straws and the like are not anchored to the filler and are washed away or blown away. The flow characteristics are high and allow continuous flow through the network. The elongated capillaries create sufficient capillary forces to draw the fluids through faster.

Additional embodiments relate to a nonwoven material, a sponge or a foam-based product, or combinations thereof, that can be cut and packed into the gutter. The need for a cover is eliminated.

It is therefore an object to provide a gutter filler material composed of fibers, foam or similar materials to form a highly orientated structure such that all pores are longer in the direction of the flow.

It is still another object to provide for a gutter filler or pack material consisting of fibers and materials having enhanced environmental resistance and mechanical properties so as to provide for durability without impairing the physical properties of the products from which they are manufactured.

It is yet another object to provide for a gutter filler or pack material consisting of fibers and materials having low density (< 10%-70% volume fraction) with sufficient resilience and porosity to allow high flow rates.

Some of the objects having been stated hereinabove, and which are addressed in whole or in part by the presently disclosed subject matter, other

objects will become evident as the description proceeds when taken in connection with the accompanying drawings and examples as best described hereinbelow.

## Description of the Drawings

Some of the objects of the invention having been stated other objects will become apparent with reference to the detailed description and the drawings as described hereinbelow.

Figure 1A is an image of a high loft nonwoven material composed of layered fibrous webs, binder fibers and other binders; and Figure 1B is a drawing of the material packed into a gutter in accordance with the present invention;

Figures 2A – 2C are graphs showing changes of average pore size as function of (a) fiber diameter and crimp and (b) Orientation Distribution Function (ODF) standard deviation and fiber crimp and (c) fiber diameter and ODF standard deviation;

Figures 3A – 3C are graphs showing changes of roundness as function of (a) fiber diameter and crimp and (b) ODF standard deviation and fiber crimp and (c) fiber diameter and ODF standard deviation;

Figures 4A – 4C are graphs showing changes of ellipticity as function of (a) fiber diameter and crimp and (b) ODF standard deviation and fiber crimp and (c) fiber diameter and ODF standard deviation;

Figures 5A – 5B show the images at (a) ODF standard deviation 10% and 30 % fiber crimp and (b) random ODF and 0 % fiber crimp;

Figures 6A – 6C are graphs showing changes of total number of pores as function of (a) fiber diameter and crimp and (b) ODF standard deviation and fiber crimp and (c) fiber diameter and ODF standard deviation;

Figure 7 is a graph of fabric type versus flow rate at 4.73 liters/minute discharge;

Figure 8 is a graph of fabric type versus flow rate at 5.68 liters/minute discharge;

Figure 9 is a graph of fabric type versus flow rate at 6.63 liters/minute discharge;

Figure 10 is a graph of volume flow efficiency of Type 1 sample at different discharge rates;

Figure 11 is a graph of volume flow efficiency of Type 2 sample at different discharge rates;

Figure 12 is a graph of volume flow efficiency of Type 3 sample at different discharge rates;

Figure 13 shows yellow thumb material (left) and black foam material (right) under a high loft sample;

Figure 14 is a graph showing Type 1 under the presence of different foams versus volume flow efficiency at 4.73 liters/minute;

Figure 15 is a graph of high loft Type 1 under the presence of different foams versus volume flow efficiency at 5.68 liters/minute;

Figure 16 is a graph of high loft Type 1 under the presence of different foams versus volume flow efficiency at 6.63 liters/minute;

Figure 17 is a graph of high loft Type 2 under the presence of different foams versus volume flow efficiency at 4.73 liters/minute;

Figure 18 is a graph of high loft Type 2 under the presence of different foams versus volume flow efficiency at 5.68 liters/minute;

Figure 19 is a graph of high loft Type 2 under the presence of different foams versus volume flow efficiency at 6.63 liters/minute;

Figure 20 is a graph of high loft Type 3 under the presence of different foams versus volume flow efficiency at 4.73 liters/minute;

Figure 21 is a graph of high loft Type 3 under the presence of different foams versus volume flow efficiency at 5.68 liters/minute;

Figure 22 is a graph of high loft Type 3 under the presence of different foams versus volume flow efficiency at 6.63 liters/minute;

Figure 23 is a graph of drainage capacity and specific drainage capacity of samples with/without foam materials;

Figure 24 is a graph of drainage time for Type 1 samples with/without foam materials;

Figure 25 is a graph of drainage time for Type 2 samples with/without foam materials; and.

Figure 26 is a graph of drainage time for Type 3 samples with/without foam materials.

## Detailed Description of the Invention

One embodiment of the subject filler material described herein is a high loft and low density (<10% - 70% volume fraction) structure that can be easily cut or molded into the right shape to pack a gutter. Figure 1A illustrates a preferred embodiment of such a product **10**, and Figure 1B shows product **10** packed into a gutter **G** in accordance with the invention.

A number of structure variables can be controlled to form the desired structure for product **10**. In particular, fiber orientation distribution, fiber crimp and fiber diameter are the controlling elements. The ODF $\psi$ is a function of the angle $\theta$. The integral of the function $\psi$ from an angle $\theta_1$ to $\theta_2$ is equal to the probability that a fiber will have an orientation between the angles $\theta_1$ to $\theta_2$. The function $\psi$ must additionally satisfy the following conditions:

$$\psi(\theta+\pi)=\psi(\theta)$$

$$\int_0^\pi \psi(\theta)d\theta=1$$

To describe the alignment of the fibers, one uses a ratio known as the Anisotropy Ratio, $f_p$ defined as:

$$f_p=2\langle\cos^2\theta\rangle-1$$

$$\langle\cos^2\theta\rangle=\frac{\int_0^\pi \psi(\theta)\cos^2(\theta_{ref}-\theta_i)d\theta}{\int_0^\pi \psi(\theta)d\theta}$$

The anisotropy parameter varies between -1 and 1. A value for $f_p$ of 1 indicates a perfect alignment of the fibers parallel to a reference direction (see Figure 5A) and a value of -1 indicates a perfect perpendicular alignment to that direction. $f_p$ is zero for a random assembly (see Figure 5B).

An oriented structure with values close to 1 would yield highly elongated structures.

A pore's shape can be determined by employing geometrical descriptors to characterize and quantify shape. Geometrical descriptors are

straightforward measurements of boundary geometry. One determines the boundary roundness ($R$) by determining the ratio of boundary area to the area of a circle whose perimeter is equal to that of the boundary as depicted below.

$$R = \frac{4\pi A}{P^2}$$

$R$ ranges from 0 to 1. Roundness is a measure of the similarity of a given shape to that of a circle.

A measure of the shape anisotropy may be obtained by the descriptor ellipticity ($E$). Ellipticity is determined by computing the lengths of the semi-major and semi-minor axes of $A_l$ and $A_S$ of a best-fit ellipse of the boundary. The lengths of the semi-major and semi-minor axes can be determined from:

$$A_l = \left(\frac{4}{\pi}\right)^{\frac{1}{4}} \left(\frac{I_{\max}^3}{I_{\min}}\right)^{\frac{1}{8}}$$

$$A_s = \left(\frac{4}{\pi}\right)^{\frac{1}{4}} \left(\frac{I_{\min}^3}{I_{\max}}\right)^{\frac{1}{8}}$$

where $I_{max}$ and $I_{min}$ are the greatest and least moments of inertia, respectively. $E$ may be calculated as:

$$E = \frac{A_l}{A_s}$$

The method employed for the measurement of roundness and ellipticity ensures that they are invariant to the geometrical transformations of rotation and translation.

In the following figures, structural variables that control behavior are demonstrated. These were created by applicants with computer simulations to illustrate idealized cases.

Figures 2A, 2B and 2C show the changes of pore size as function of fiber crimp, ODF anisotropy, and fiber diameter. For the same web density, an increase of fiber diameter reduces the total number of fibers per unit area lowering the total number of crossovers per unit area. This results in increased average pore size.

It is interesting to note that an increase in fiber crimp results in smaller average pore size. An increase in fiber crimp causes a shift in the distribution towards smaller pores in anisotropic structures. This occurs because an increase in crimp increases the number of crossovers especially in the direction perpendicular to the fiber axis. In random structures, the number of crossovers remains the same and increasing fiber crimp will have little or no effect on pore size.

Figures 3A – 3C and 4A – 4C show the results for roundness and ellipticity as a function of fiber diameter and crimp as well as structure anisotropy. It may be noted that increasing fiber crimp in a given structure results in rounder, less elongated pores (see Figures 3A and 4A). The combined effect of structure anisotropy and fiber crimp are shown in Figures 3B and 4B. Here, at low levels of crimp, the effect of structure anisotropy is significant. As crimp increases however, the structure anisotropy becomes less dominant as many pores are small and round. Consequently, for large values of crimp, there is little or no difference between the pore shapes at different levels of anisotropy. As may be seen from Figure 5A, a high level

of crimp has resulted in the formation of many small pores while a few large elongated pores remain, the pore size and shape are similar to those in a random structure shown in Figure 5B. These average values, however, must be used with caution in that the large pores in the high anisotropy structures are probably affecting other important properties such as flow, strike through and mechanical behaviors. The combined effect of fiber diameter and structure anisotropy is shown in Figures 3C and 4C. Here, the effect of structure anisotropy on shape is dominant. Smaller fiber diameters are expected to result in a larger number of pores and do not affect the pore shape.

The total number of pores as a function of fiber diameter and crimp and structures anisotropy is shown in Figures 6A – 6C. It may be noted that that fiber crimp results in a significant increase in the number of pores (see Figure 6A). The combined effect of structures anisotropy and fiber crimp are shown in Figure 6B. Both appear to have a significant effect on the number of pores. The effect of structure anisotropy for different fiber diameters is shown in Figure 6C. The effect of fiber diameter is clear.

Thus, one preferred embodiment of the invention is a filler or pack material **10** with high compressive resilience, high porosity, low density (less than 10% - 70% volume fraction) and preferably elongated pores to assist in the flow of the liquids. A random structure with more round and isotropic pores will also work, but would have lower fluid flow characteristics compared to a structure with elongated pores at the same density.

The density (preferably less than 10% - 70% volume fraction) can be also controlled by fiber diameter. There is an interaction between fiber size,

fiber orientation distribution, overall porosity and pore size distribution. Higher porosities can be achieved by using thicker fibers. Compressive resilience can also be improved by using thicker fibers. However, the overall flexibility of the structure will also reduce making it more difficult to cut and fit the filler material **10** in the gutter. These attributes must be balanced to achieve the highest resilience, highest porosity, and highest flexibility.

One advantageous method to make a filler material **10** of the type described is by the use of expandable foam to form a sponge. Alternatively, the structure may be made as in high loft nonwovens where fibers are formed into a web by a web formation device such as carding, airlay, wetlay or a combination thereof or other methods such as meltblowing and/or spunbonding. These webs may be stacked together to form a laminate structure or can be formed into a three dimensional embodiment by the use of mechanical bonding methods. These fibers and /or webs are then fused together, bonded by the addition of a resin, a powder, another low melt fiber or a combination thereof or by the use of resins and adhesives. Alternatively, the fibers may be bi-component, or multi-component, wherein one component would melt at a lower temperature bonding the structure together. The fibers used therein can be synthetic, man-made or natural.

Applicants contemplate that novel filler material **10** may comprise homocomponent, bi-component or multi-component fibers, and both solid and hollow fibers. Further, the filler material **10** may comprise multifilament or staple fibers having a diameter of 15 denier or less as well as multifilament and monofilament fibers having a diameter greater than 15 denier. Further, the filler material **10** may comprise fiber or foam or a

combination thereof formed from polyolefins, polyamides, polyester and co-polymers, natural fibers and combinations thereof. Additionally, filler material **10** may comprise sheath/core fibers comprising sheaths that melt at a lower temperature than the fiber cores. Filler material **10** may comprise both fibers and non-fibrous elements such as foam and sponges, and the filler material **10** may be formed from woven, knitted, braided or non-woven material.

The web formation processes typically lead to an oriented structure wherein the majority of fibers are parallel to the direction in which the web is being formed and collected (machine direction). The layering is preferably done so as not to realign these fibers as the orientated structure is expected to lead to better fluid flow behavior.

It is contemplated by applicants that the novel filler material **10** may include other embodiments to aid in durability, environmental resistance or overall performance.

Finally, it is believed that other materials may be used instead of or together with fibers to form filler material **10**. That is, the same process may be used to incorporate other foams, yarns and fibers, fabrics and other such solids. Therefore, additional functionality or multiple functionality is achieved by the use of multi-component fibers, foams and other materials.

## EXPERIMENTAL TESTING

There are not any widely accepted definitions describing a highloft nonwoven. One definition is: Nonwovens that are more than 1/8 inches in thickness and contain much more air or voids than fiber. Another definition

is: A low density fiber network structure characterized by a high ratio of thickness to weight per unit area. The fibers can be continuous or discontinuous, bonded or unbonded. Highloft battings have no more than 10% solids, by volume, and are greater than 3 mm (0.13 inch) in thickness.

## I. SAMPLE MATERIALS

### A. Fabric Samples used in Volumetric Flow Rate Tests

In measuring Volumetric Flow Rate, 3 different types of highloft samples were precut and chosen. The samples were evaluated according to their thickness and areal mass density. The characteristics of each sample type are shown in Table 1.

**Table 1 The Characteristics of Test Samples**

| I.D of sample | Fabric Dim. (inch) | Fabric Dim. (cm) | Fabric Layers | A.M.D. ($g/m^2$) | Fiber Denier | Fiber density ($g/cm^3$) |
|---|---|---|---|---|---|---|
| | length x width x height | length x width x height | | | | |
| Type 1 | 40 x 4 x 4 | 101.6 x 10.2 x 10.2 | 24 | 1221 | 14.79 | 1.38 |
| Type 2 | 40 x 4 x 4 | 101.6 x 10.2 x 10.2 | 45 | 2289 | 15.88 | 1.38 |
| Type 3 | 40 x 4 x 5 | 101.6 x 10.2 x 12.7 | 44 | 2746 | 15.34 | 1.38 |

In Table 1, A.M.D stands for Areal Mass Density of the samples.

Samples were produced from 100% polyester fibers with;

- 85% 15 denier PET
- 15% sheath/core Co-Pet binder fibers

According to Table 1, I.D of sample indicates the specific numbering system used to characterize the sample. According to that, I.D numbers indicate the following;

- Type 1: 4 inches thick sample and one square foot of the sample weighs 4 ounces. (1221 g/$m^2$)
- Type 2: Sample that is 4 inches thick and one square foot of the sample weighs 7.5 ounces. (2289 g/$m^2$)
- Type 3: Sample that is 5 inches thick and one square foot of the sample weighs 9 ounces. (2746 g/$m^2$)

Since these samples were made by using drafted cross lappers, the majority of the fibers are oriented in x-y plane, with many being roughly at 45° or 135° to either the machine direction or cross direction.

One lap of a crosslapper is one complete cycle. Each lap forms two layers in the sample. If one multiplies the number of laps by the number of cross lappers on the production line, one can get the number of layers in the samples. For example, the normal set up on the line would produce 24 layers for 4 inches thick, 4 oz/$ft^2$ product and thus 45 layers for 4 inches thick, 7.5 oz/$ft^2$ product.

The fluid medium used in applicants' study was city water supplied from a laboratory faucet.

<u>Weight of Samples</u>

The weights of samples were measured by OHAUS ES 50L (50 x 0.02 kg) type of scale and were recorded in Table 2.

<u>Thickness of Samples</u>

Sample thickness was determined using Compression Tester Thickness Machine (KAWABATA Evaluation System-3) and were recorded in Table 2.

**Table 2 Measured characteristics of samples**

| I.D of sample | Fabric Dim. (cm) length x width x height | Sample weight (g) | Sample volume ($cm^3$) | Sample Density ($g/cm^3$) | Fiber Density ($g/cm^3$) |
|---|---|---|---|---|---|
| Type 1 | 101.6 x 10.2 x 10.2 | 125.99 | 10487.7 | 0.012 | 1.38 |
| Type 2 | 101.6 x 10.2 x 10.2 | 236.24 | 10487.7 | 0.023 | 1.38 |
| Type 3 | 101.6 x 10.2 x 12.7 | 283.49 | 13109.7 | 0.022 | 1.38 |

B. Fabric Samples Used in Water Drainage Tests

Fabric samples used in drainage tests were of the same type as used in volumetric flow rate tests. Sample lengths and widths were the same but the thickness (Type 1 and Type 2 had 4 inches of thickness; Type 3 had 5 inches). For each type of fabric, two samples were precut and weighed. Table 3 shows fabric sample weight used in drainage tests.

**Table 3 Sample characteristics used in Drainage Tests**

| | Weight of sample (grams) | Length (in) | Width (in) | Thickness (in) |
|---|---|---|---|---|
| Type 1 | 5.04 | 1.5 | 4 | 4 |
| | 5.4 | 1.5 | 4 | 4 |
| Type 2 | 10.68 | 1.5 | 4 | 4 |
| | 10.55 | 1.5 | 4 | 4 |
| Type 3 | 9.82 | 1.5 | 4 | 5 |
| | 9.66 | 1.5 | 4 | 5 |

Drainage tests were done using these samples with/without foam materials having the same base area of fabric samples and thus covering the bottom surfaces of the fabrics.

### C. Foam Materials Used in Volumetric Flow Rate and Water Drainage Tests

There are two kinds of foam materials utilized in the tests and placed beneath the fabric samples in the simulated gutter:

- 1/8 inch thick, 90 pores per inch (yellow colored)
- 1/8 inch thick, 20 pores per inch (black colored)

## II. TEST RESULTS

### A. Volumetric Flow Rate and Efficiency

#### Effect of Discharge Rate

The results of the tests will be discussed by providing both the data obtained from tests and statistical analysis to draw reasonable conclusions.

As mentioned earlier, each test had 4 runs, first observations always being lower than the rest of the 3 observations. The reason is that samples get saturated in the first place while holding most of the sprayed water inside them and transferring little water within the first 2 minutes. Then, after saturation, water is transferred according to the structural characteristics of the samples without being stored inside the pores, because the samples were already saturated within the first 2 minutes. So, the three following observations have higher values, which is reasonable.

Because of this situation, it is necessary to classify the test results as saturated and unsaturated. Also, when one takes take a look at rainy weather conditions, one sees that rain starts slowly and maintains an average fall down for the majority of the time and then stops. This is why tests were done on a continuous manner.

As expected, when the charge rate increases, flow through the highloft nonwoven samples increases as a result of more volume of water is sprayed over the samples per unit time.

For the purpose of comparing results with a control group, the Rain Machine testing device (which simulates a roof and gutter system) was run without any type of samples or foam materials to find out the maximum volumetric flow rate and efficiency. Also, theoretical flow (assuming no loss of water) was considered so that in case of water loss it could be calculated. Table 4 illustrates the results obtained by running the Rain Machine without any samples or foam materials. Three different discharge rates were used 4.73-liters/min., 5.68-liters/min, and 6.63-liters/min.

**Table 4 Control flow without any type of highloft or foam material**

| Water discharge (liters/min) | Amount of water transfer (liters) | | | | Average | Std. Dev. |
|---|---|---|---|---|---|---|
| 4.73 | 4.11 | 4.44 | 4.42 | 4.48 | 4.36 | 0.17 |
| 5.68 | 5.11 | 5.29 | 5.31 | 5.30 | 5.25 | 0.10 |
| 6.63 | 5.87 | 6.23 | 6.37 | 6.34 | 6.20 | 0.23 |

Also, Table 5 shows the theoretical flow, which assumes no water loss.

**Table 5 Theoretical flow**

| Water flow (liters/min) | Amount of water transfer (liters) |
|---|---|
| 4.73 | 4.73 |
| 5.68 | 5.68 |
| 6.63 | 6.63 |

From the tables above, it can be understood that there is a loss of water in the system. The reason of water loss is that since water comes out of spray nozzles intensely, some of the tiny water particles fly away from the Rain Machine after hitting the simulated roof surface, thus causing not all the sprayed water flow down into gutter.

The amount of water loss is 0.4 liters/min. This data was computed to each testing result obtained and necessary corrections were made while calculating flow rates and efficiencies.

According to results found in Table 4 and Table 5, Table 6 was prepared. Table 6 illustrates the efficiencies of the Rain Machine when the machine was run empty (without samples or foam materials).

**Table 6 Rain Machine Efficiencies without samples or foam materials**

| Water flow (liters/min) | Efficiency (%) | Std error |
|---|---|---|
| 4.73 | 94.52 | 0.09 |
| 5.68 | 93.71 | 0.05 |
| 6.63 | 96.27 | 0.11 |

As one can see from Table 6, the Rain Machine works with an efficiency of 96.27% (maximum) and 93.71% (minimum).

<u>Effect of Sample Density</u>

There are three different types of highloft samples used in the tests, each having different densities. These samples are 400C400C, 400C750C, and 500C900C having densities of 1221 g/m$^2$, 2289 g/m$^2$, and 2746 g/m$^2$, respectively. No foam material is used in these tests.

While choosing the samples, the structural characteristics were considered to be critical such as density because samples having too low a density would have had too open a structure and would not have acted as a filler for usage in a gutter whereas very dense samples would have been an obstacle to a good flow. Table 7, Table 8 and Table 9 show the test results of average flow rates (both unsaturated and saturated conditions) for the three different types of samples under three discharge rates.

**Table 7 Flow Rate of different samples each having different densities at 4.73 liters/min**

| Water Discharge (liters/min) | Fabric Type | Flow Rate (liters/min) (Unsat) | Flow Rate (liters/min) (Sat) | Std.Err. (Unsat) | Std.Err. (Sat) |
|---|---|---|---|---|---|
| 4.73 | Type 1 | 4.10 | 4.39 | 0.30 | 0.06 |
| 4.73 | Type 2 | 4.27 | 4.42 | 0.15 | 0.01 |
| 4.73 | Type 3 | 4.20 | 4.38 | 0.19 | 0.02 |

**Table 8 Flow Rate of different samples each having different densities at 5.68 liters/min**

| Water Discharge (liters/min) | Fabric Type | Flow Rate (liters/min) (Unsat) | Flow Rate (liters/min) (Sat) | Std.Err. (Unsat) | Std.Err. (Sat) |
|---|---|---|---|---|---|
| 5.68 | Type 1 | 4.96 | 5.33 | 0.37 | 0.03 |
| 5.68 | Type 2 | 4.85 | 5.30 | 0.46 | 0.26 |
| 5.68 | Type 3 | 4.74 | 5.28 | 0.55 | 0.10 |

**Table 9 Flow Rate of different samples each having different densities at 6.63 liters/min**

| Water Discharge (liters/min) | Fabric Type | Flow Rate (liters/min) (Unsat) | Flow Rate (liters/min) (Sat) | Std.Err. (Unsat) | Std.Err. (Sat) |
|---|---|---|---|---|---|
| 6.63 | Type 1 | 5.61 | 6.02 | 0.41 | 0.02 |
| 6.63 | Type 2 | 5.74 | 6.21 | 0.47 | 0.01 |
| 6.63 | Type 3 | 5.61 | 6.24 | 0.63 | 0.02 |

In Tables 7, 8 and 9; Type 1, 2 and 3 indicates 400C400C, 400C750C, and 500C900C, respectively. Normally, it is expected that Type 1 sample should give the highest flow rate since it has the more open structure than the other types. When one looks at the above tables, this is true for Table 7 but not for the others. In Table 7, Type 2 sample has the best flow rate whereas on Table 8 and Table 9, the best flow rates are produced by Type 1 and Type 2 samples, respectively. However, when one takes a look at the overall results, it is possible to see that there is no significant difference among the flow rates of samples which is quiet interesting. One normally should expect a significant difference in the performance but this is not the case. The reason for this is because the flow is limited by the diameter of the downpipe, which is a parameter of flow rate in rain gutter applications.

Figure 7, Figure 8 and Figure 9 shows the flow rates according to different densities of fabric samples. It is possible to see that the samples follow a similar behavior in terms of water transfer from these figures as well. It is believed that these fabric samples should have different permeabilities and penetration rates with Type 1 having the best permeability and Type 2 and Type 3 having similar permeabilities and penetration rates. The permeability and penetration rates were not studied in this study since they require sensitive and precise measuring methods and testing devices. The Rain machine test device is not capable of measuring these characteristics.

As mentioned earlier, the samples have similar volumetric flow rates and thus efficiencies. The other approach to explain this situation might be related with the behavior of saturated fabrics under continuous flow. Once

fabric pores are saturated with water, assuming samples have very similar or same pore size distribution and mean pore size and turtuosity, this is possible.

While testing the samples in the gutter, gravitational force affects the samples also and pulls down the samples while draining the water into water tank. Thus, it might be very possible that this is another factor affecting and limiting the performance of the fabric samples.

The efficiencies of the samples were also considered. When one takes a look at the efficiencies, one sees the same trend as volumetric flow rates, which is reasonable. Figure 10, Figure 11, and Figure 12 illustrate the volumetric flow efficiencies of the samples under three discharge rates.

From the Figures 10, 11 and 12, Type 2 and Type 3 samples behave similar to each other. When one looks at their characteristics, one sees that their numbers of layers are almost the same (Type 2 has 45 and Type 3 has 44 layers). Their thicknesses are different, Type 2 is 4 inches and Type 3 is 5 inches. One may expect different flow behavior but since the 5 inch sample was not totally inside the gutter, only 4 inches of the fabric was in contact with the flow of water, and its behavior was similar to that of Type 2.

On the overall, samples had volumetric flow efficiencies between 90-94% depending on the conditions. The results match with the expected performance of the samples, which are all lower than the Rain Machine efficiency when no samples or foam materials were used.

Effect of Foam Material Type

There are two different kinds of foam material used in the tests.

- Yellow Foam – 1/8 inch thick, 90 pores per inch
- Black Foam – 1/8 inch thick, 20 pores per inch

Figure 13 shows both yellow and black foams under a highloft sample.

Foam materials used in tests are very light materials and their density is less than water, thus they float on water. When utilized under a highloft sample inside a gutter system, it is expected that the foams apply a push-up force to the fabrics and ease the flow of water inside the gutter. Foam materials ease the flow from the fabric to the gutter because they have highly porous structure. Also, foam materials allow drainage.

According to test results, in some cases, foam materials performed well and increased flow rates compared to tests where only fabric samples were used with no foam. However, this is not true for all cases and for each foam material.

Table 10 shows the results obtained from all of the tests.

**Table 10 Overall Test Data for Vol. Flow Rate**

| | Water Discharge | Fabric Type | Flow Rate (liters/min) (Unsat) | Flow Rate (liters/min) (sat) | Std.Err.Un | Std.Err.Sat |
|---|---|---|---|---|---|---|
| No Foam Material | 4.73 liters/min | Type 1 | 4.10 | 4.39 | 0.30 | 0.06 |
| | | Type 2 | 4.27 | 4.42 | 0.15 | 0.01 |
| | | Type 3 | 4.20 | 4.38 | 0.19 | 0.02 |
| | 5.68 liters/min | Type 1 | 4.96 | 5.33 | 0.37 | 0.03 |
| | | Type 2 | 4.85 | 5.30 | 0.46 | 0.26 |
| | | Type 3 | 4.74 | 5.28 | 0.55 | 0.10 |
| | 6.63 liters/min | Type 1 | 5.61 | 6.02 | 0.41 | 0.02 |
| | | Type 2 | 5.74 | 6.21 | 0.47 | 0.01 |
| | | Type 3 | 5.61 | 6.24 | 0.63 | 0.02 |
| Yellow foam (90 ppi) | 4.73 liters/min | Type 1 | 4.02 | 4.41 | 0.40 | 0.03 |
| | | Type 2 | 3.81 | 4.44 | 0.63 | 0.01 |
| | | Type 3 | 3.87 | 4.45 | 0.59 | 0.02 |
| | 5.68 liters/min | Type 1 | 4.74 | 5.20 | 0.46 | 0.02 |
| | | Type 2 | 4.55 | 5.27 | 0.72 | 0.03 |
| | | Type 3 | 4.77 | 5.30 | 0.54 | 0.01 |
| | 6.63 liters/min | Type 1 | 5.51 | 6.11 | 0.60 | 0.05 |
| | | Type 2 | 5.58 | 6.13 | 0.55 | 0.04 |
| | | Type 3 | 5.67 | 6.34 | 0.68 | 0.01 |
| Black foam (20 ppi) | 4.73 liters/min | Type 1 | 4.22 | 4.40 | 0.18 | 0.03 |
| | | Type 2 | 4.18 | 4.43 | 0.25 | 0.02 |
| | | Type 3 | 4.04 | 4.44 | 0.41 | 0.01 |
| | 5.68 liters/min | Type 1 | 4.92 | 5.28 | 0.36 | 0.01 |
| | | Type 2 | 4.89 | 5.28 | 0.40 | 0.01 |
| | | Type 3 | 4.86 | 5.30 | 0.45 | 0.01 |
| | 6.63 liters/min | Type 1 | 5.90 | 6.32 | 0.42 | 0.02 |
| | | Type 2 | 5.77 | 6.28 | 0.52 | 0.02 |
| | | Type 3 | 5.80 | 6.17 | 0.37 | 0.03 |

When compared, it can be seen that the first observations (flow rates-unsaturated) in Table 10 are smaller than the first observations for all discharge rates in Tables 7, 8 and 9. This means for the first observations, yellow and black foams have smaller volumetric flow rates than the tests where only fabric samples were utilized. The reason for that is related with

what happens in the first 2 minutes. Most of the water is captured inside the pores of the fabric, thus saturated the fabric and foam materials did not have enough water flowing under them to apply a push up force to the sample. Thus, foam materials acted like a barrier or another layer added up to the fabric thus decreasing the flow rate during that time.

Interestingly, most of the saturated flow rates for both foam materials in Table 10 are larger than no foam data. This is because the fabrics were already saturated and started to transfer the water instead of capturing it. This lead to water accumulation under the foam materials and a push-up force was generated by them thus easing the flow of water and increased water flow efficiencies.

Figures 14 – 22 illustrate the volumetric flow efficiencies of foam materials and also it is possible to see and compare them with the test results where no foam materials used (without foam).

B. Drainage Behavior

Effect of Fabric Density and Foam Material Type

Drainage capacities of the samples were calculated as follows;

$$Drainage\ \ Capacity\,(\,C\,)(\,grams\,) = W_i - W_f$$

where;

$W_i$: Initial weight of the water inside the drainage box at the beginning of the test

$W_f$: Final weight of the water inside the drainage box at the beginning of the test

**Table 11 Drainage Capacity (grams) of samples with/without foam materials**

| | Type 1 | Type 2 | Type 3 |
|---|---|---|---|
| No Foam | 311.7 | 160.5 | 253.3 |
| Yellow (90 ppi) | 294.5 | 185.2 | 253.3 |
| Black (20 ppi) | 278.9 | 185.9 | 197.6 |

Type 1 sample (see Table 11) had the maximum drainage capacity where no foam was used and Type 2 sample had the minimum drainage capacity where no foam was used. This is due to the sample porosity. Type 2 is less porous than sample 1, thus holding more water at the end of test compared to sample 1. For the same volume of Type 1 and 2, Type 1 has 24 layers whereas Type 2 has 44. Thus, Type 2 is more packed. In terms of permeability, Type 2 is less permeable than Type 1. Also, mean pore size of Type 2 sample should be lower than Type 1. The larger pores would allow more drainage compared to smaller pores. This could be the other reason why Type 1 had better drainage. Type 3 has 44 layers but its thickness was 5 inches thus, it was less packed than Type 2. This could be the reason why Type 3 had the medium drainage capacity. This were summarized in Figure 23.

In terms of foam material type effect on drainage, these did not increase the drainage for Type 1 sample, whereas both of the foam materials increased it for Type 2. For Type 3, yellow foam increased the drainage capacity whereas black foam decreased it.

When one takes a look at Figure 18, the yellow foam material specific drainage for Type 3 and 2 is higher than the ones with no foam for the same

categories whereas this is the opposite for Type 1 fabric. The effects of foam materials increase as the samples get more packed.

Black foam material only increases the drainage at the densest type of sample, which is Type 2. For other types, it did not increase drainage, actually resulted with a decrease in results.

It is also beneficial to look at the drainage times of these scenarios and make conclusions about how they performed in terms of draining time. Figures 23, 24, 25 and 26 summarize the test results. Yellow foam material has the longest drainage time for all of the samples whereas black foam's drainage time is almost the same as the test results where no foam was used.

It will be understood that various details of the subject matter described herein may be changed without departing from the scope of the invention. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation, the invention being defined by the claims set forth below.